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A micromethod for the determination of paramagnetic susceptibility of substances in dilute solutions

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With 9 figures in the text

Introduction

The purpose of the construction of the apparatus described here was to determine the paramagnetic susceptibility of the iron in some peroxide compounds of catalases and peroxidases which are not stable in aqueous solutions containing more than 10 γ enzyme iron per ml. However, when studying other hemin-enzyme compounds, which are stable in higher concentrations, a micromethod is important because it requires only a small quantity of the precious material. The method is not restricted to biochemical work but is also applicable to the investigation of paramagnetism in general in dilute aqueous or nonaqueous solutions, e.g. salts of the lanthanide or the actinide elements.

The apparatus was designed with the view of making measurements quickly and easily.

Principle

The apparatus is an improvement of an earlier one described by Theorell (1), a modified form of which has also been used by Howland and Calvin (2, 3). This older method is a variation of the well known Gouy-method with a horizontal tube in a bifilar suspension. The displacement of the tube in the magnetic field is measured. As the tube is allowed to move in the field it must be made rather long in order to avoid errors. Thus in this case a large part of the tube is "dead weight", contributing very little to the magnetic force but decreasing the sensitivity of the forcemeasuring system in proportion to its weight.

Higher sensitivity may be obtained by utilizing a shorter tube. In such a case the gradient of the magnetic force along the axis is no longer negligible at the ends of the tube and would cause nonlinearity in the readings if the tube is allowed to change its position during the measurements. Errors are also introduced if the reference position of the tube is not well defined. It is possible to obtain both linearity and accuracy if the initial position of the tube relative to a fixed index is maintained in the field by moving the fixing points of the suspending wires so as to compensate the magnetic force.

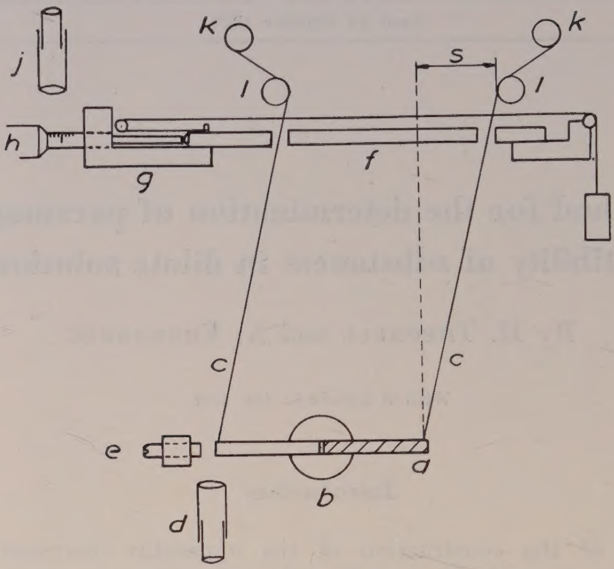

Fig. 1. Main principle of the apparatus.

Fig. 1 schematically illustrates the main principle of the apparatus. A view in the direction of the central magnetic field with the front magnet pole not shown is presented. The tube (*a*) between the poles (*b*) is suspended by two thin wires (*c*). Its position relative to the fixed screw (*e*) is observed in the microscope (*d*). The upper ends of the wires are kept in position by a score in each of the cylinders (*l*) and fixed on the unrolling cylinders (*k*). These four cylinders are mounted on the slide (*f*), whose movement in the guide (*g*) is controlled by the micrometer (*h*). The slide is maintained firmly against the head of the micrometer by the lead weight (*i*). The displacement (*s*) of the slide is read on the micrometer by the aid of a readingglass (*j*).

A total view of the apparatus is shown in fig. 2.

The magnet

The magnet was designed to obtain maximum sensitivity. For this it is necessary that the integral of $\left| H_y \frac{\partial H_y}{\partial x} \right|$ over the half volume of the tube is great. (See such standard texts as Klemm: Magnetochemie or Selwood: Magnetochemistry). Since the tube is short, the maximum of $H_y \frac{\partial H_y}{\partial x}$ (See fig. 3) must be both high and sharp. This is achieved by a magnet producing an intense field in a small region around which the field strength decreases rapidly.

The outlines of the magnet are shown in fig. 4. It was constructed by Dr. Dreyfus at ASEA, Västerås, Sweden, and with his permission we cite from a private communication:

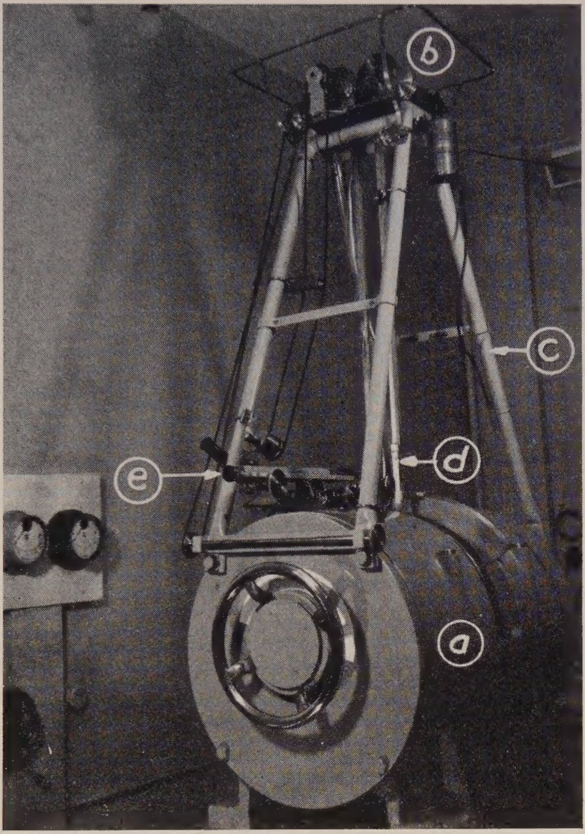

Fig. 2. Total view of the apparatus with magnet (*a*), guides (*b*), welded stand (*c*), wire shieldings (*d*) and reading glass (*e*).

"The magnet is designed to give intense fields in an interferricum of 9 mm diameter and 5.5 mm length. The size of the magnet was determined by allowing 40 cm for the inner diameter of the magnet housing. The earlier magnet (du Bois, largest type) had 100 000 ampere turns at 6 kW effect consumption and gave an induction in the airgap of 30 000 gauss. These figures show that the number of ampere turns was not efficiently used. ASEA's construction therefore was directed to obtaining a higher airgap induction at fewer ampere turns with less effect consumption.

A well dimensioned electromagnet with high airgap induction must have a certain balance between the "maximum specific induction" of the iron ($4\pi J \cong 21\,400$ gauss), the number of ampere turns ($I N_\delta$) for the airgap and two pole tips, and the maximum diameter of the pole tips (d). The latter should be chosen large enough, so that at the change from the conicity of the pole tip (120° top angle) to that of the core (about 90° top angle) the iron induction (B) has fallen below the saturation value ($4\pi J$). This will happen if

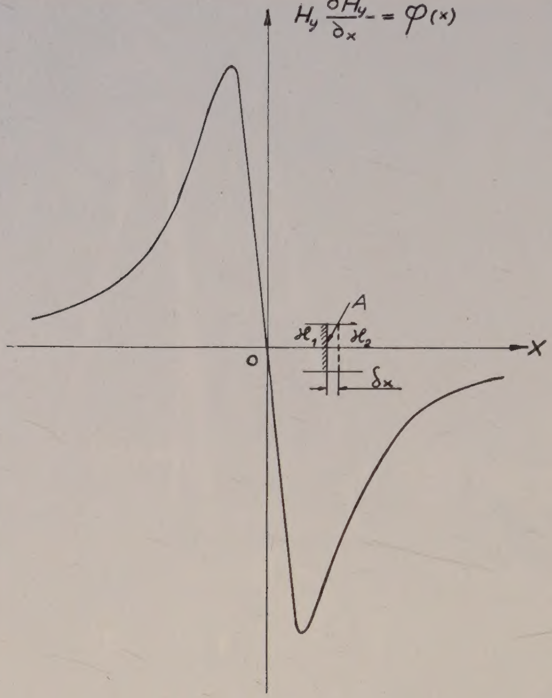

Fig. 3. Curve showing the variation of the magnetic force, $Hy \frac{\partial Hy}{\partial x}$, along the axis of the tube.

$$d \geq 3.8 \frac{I N_\delta}{4 \pi J},$$

where d is in cm. Accordingly the magnet was wound for 60 000 ampere turns, of which about 56 000 were used for the airgap and the two pole tips. Hence the outer diameter of the latter was $d = 10$ cm. From this value the diameter of the core on which the pole tips are fixed was allowed to increase continuously to 19 cm to allow the considerable flow of the leakage field to pass at an induction below 20 000 gauss. The pole tips and the core are made of common forge iron containing 0.1—0.15 % and 0.35 % carbon respectively. The magnet housing is made of steel castings, and each core with bed plate and coil can be moved 5 cm along their axis. This is done manually by means of a wheel on a thread casing when the magnet current is off.

On each core the windings are divided in two coils, each wound with 850 turns of 2.6 mm copper wire, so that the total number of turns is 4 × 850 = = 3 400 turns. With a hot resistance of about 11 ohms and an applied voltage of 220 volts the greatest number of ampere turns is 20 × 3 400 = 68 000 and the maximum effect consumption is 4.4 kW. The magnet was not intended for continuous operation with full current, but to diminish slight temperature increases three water cooled flanges were arranged on each core to form the

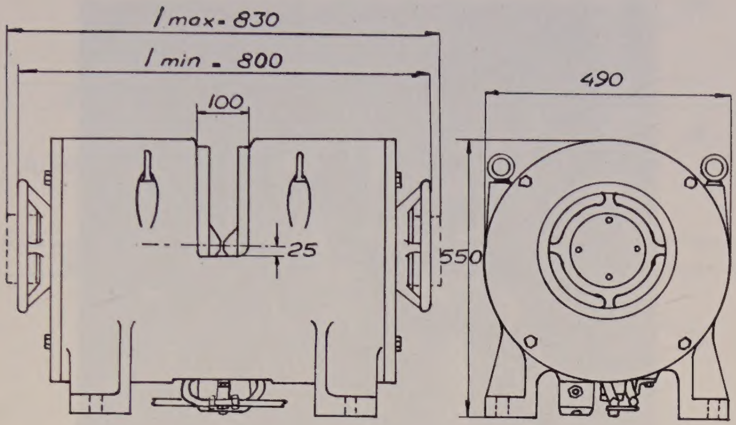

Fig. 4 Outlines of the magnet.

bobbins of the two coils. This also diminishes the heat flow from the coils to the airgap. The copper weight of the magnet coils is 150 kg and the weight of the whole magnet 740 kg."

The maximum airgap induction was found to be 44 000 gauss for 68 000 ampere turns when the distance between the end planes of the pole tips was 6 mm. In practise, however, a distance of 9.8 mm at the same number of ampere turns was employed. From measurements made on the giant magnet at Uppsala University (4) it is possible to calculate the airgap induction under these conditions to be about 39 000 gauss.

The magnet is mounted on a vibrationfree concrete foundation on solid rock.

Two dc motor-generators in parallell, delivering 220 V and 20 A each, serve as the power supply. A variable resistance of about 800 Ω in series with the magnet is used to regulate the current. It is made of wires with increasing diameter to withstand the increasing current. By these means it is possible to regulate the magnet current at 20 A within 0.05 A. A resitor of 38 Ω is placed in parallell with the magnet coils and the ammeter. It serves as a discharing resistance for the magnet inductance when the current falls rapidly or is switched off directly. This prevents arc formation in the relay switch and also protects the series resitor from damage if there should be a bad contact.

It is convenient for the sake of rapidity to switch the current on and off directly when slide deflections of less than 300 μ are encountered. In such case the tube does not move out of the view of the microscope and possible effects of hysteresis are small compared with other errors. When greater forces are measured the current is always smoothly regulated to avoid hysteresis errors.

During the time it takes to adjust the tube with the micrometer the current occasionally decreases about 0.1 A. This is due to heating in the circuit. Since the pole tips are saturated or nearly so at 20 A, this small change in current causes only a small error in the reading. However, if higher accuracy is wanted it would be desirable to use a good current stabilizer.

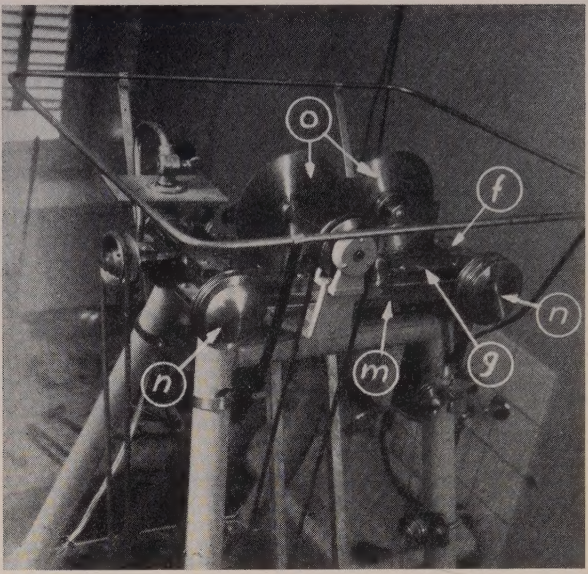

Fig. 5. View of the guide system on the top of the stand.

Guide system and adjusting equipment

The welded stand (*c*) of fig. 2 is made of steel tubes of outside diameter 1 $\frac{3}{16}$ inches. It is about 80 cm high and has been found to be perfectly stable. The guides for regulating the position of the sample tube are mounted on the top of the stand. See fig. 1 and 5 and the previous description of the principle. The guide (*g*) and its slide (*f*) are used for the measurement of the magnetic force. *g*, which is called the main guide, forms the slide of another guide (*m*) in the perpendicular direction. This slide is used to adjust the position of the tube between the pole tips and is moved by the two screws (*n*), against which it is held by two strong coil springs. The guides and the unrolling-cylinders (*k*) can be operated from the base of the stand by means of wire transmissions. The two big cog-wheels (*o*) serve to synchronize the unrolling-cylinders. Their action can be made independant of each other thus allowing the tube to be adjusted to a horizontal position. One of the guiding cylinders (*l*) is movable along its axis, so that it is possible to adjust the tube perpendicular to the central field.

Tube-box and observation system

A bar of aluminium is mounted across the yoke of the magnet just under the pole tips. On this bar and between the pole tips a small box is built, where the sample tube is situated during the measurements. See figs. 6 and 7.

The endscrews (*a*) and the thick endwalls (*b*) of the tube box are made of iron. This is an attempt to diminish the field near them and thus also the

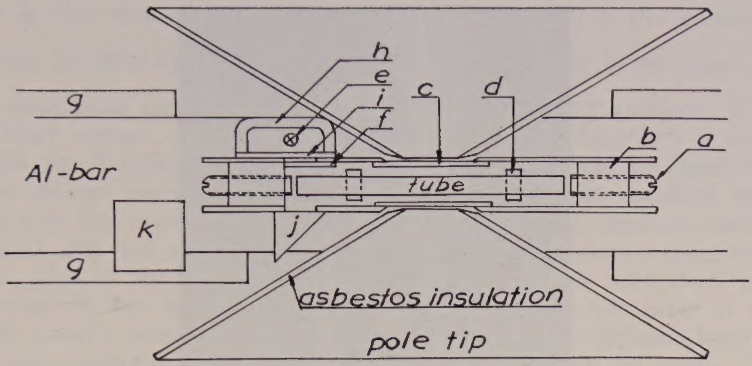

Fig. 6. Vertical view of the tube-box.

errors at the end of the tube due to irreproducible filling. The walls (*c*) in the middle of the box are made of plexiglas to diminish heat conduction between the box and the pole tips. The other walls are made of brass.

Two adjustable bars (*d*) with sharp edges emerge through holes in either end of the box. By a graduated wheel the bars may be individually lifted up to make contact with the tube in order to determine whether it is in horizontal position.

A small lamp (*e*) gives a diffuse light for the microscope through the white plexiglass window (*f*). This lamp must be fed with dc. With ac the pulsating magnetic force will destroy the filament at once.

If no arrangements are made for keeping the temperature constant in the box, the heating from the lamp (0.5 W) causes a temperature difference between the ends of the tube of about 2° C. This is enough to cause a rather large error in the readings. To avoid this a water thermostate was installed, the water being pumped through a system of cooling tubes (*g*) in the aluminium bar and also through the lamphouse (*h*). When the right endscrew is removed a thermometer can be inserted in the box for temperature measurements.

The light to the microscope is reflected by a 6 mm right angle prism (*j*) to a larger one (*k*) of 12 mm, from which it is sent through the vertical tube (*l*). The microscope objective is situated in the lower end of this tube. A third prism in the upper end of (*l*) throws the light through a horizontal tube (*e* of fig. 2) to the ocular. The objective and the third prism can be moved vertically independently in order to adjust sharpness and view of the field respectively. The total magnification is about 160 times.

A system of four u-formed gutters of brass shielding around each of the suspension wires serves to avoid errors caused by air currents. The upper pairs are fixed by hinges attached to the bottom of the main guide. They are swung out and fixed to the stand when not in use. The inside ones of the lower pairs form the roof of the box, and can be removed readily. The outside ones are fixed to the magnet housing and support the table, which is used for the filling of the tube. It will be described later.

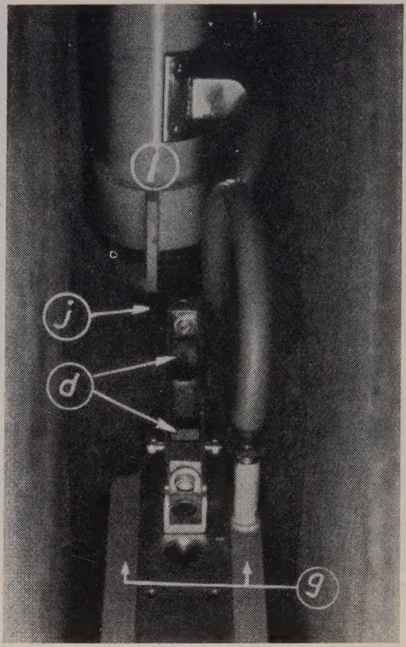

Fig. 7. Side view of the tube-box between the pole tips seen through the opening in the yoke.

Tube construction

The magnetic force acting on a body on the x-axis of fig. 3 is

$$f = \int_{x_2}^{x_1} A\,\varkappa\,H_y \frac{\partial H_y}{\partial x}\,d\,x \tag{1}$$

and it is directed along the axis. A is the cross-sectional area and $\varkappa$ the volume susceptibility. Assume that the shape of the body is symmetrical with respect to a plane perpendicular to the x-axis and containing its origin 0. If $\varkappa$ is constant for each part, the difference being $\Delta\,\varkappa$, the resulting force is

$$F = \Delta\,\varkappa \int_{0}^{x_1} A\,H_y \frac{\partial H_y}{\partial x}\,d\,x = \Delta\,\varkappa\,J \tag{2}$$

With the total mass of the body $= M$ and the length of the suspending wires $= L$ we get the sensitivity

$$\sigma = \frac{s}{\Delta\,\varkappa} = \frac{J}{M\,g}\,L, \tag{3}$$

where s is the displacement of the main guide and g is the acceleration due to gravity. In this equation the quotient $\left(\frac{J}{M\,g}\right)$ has to be as large as possible to give maximum sensitivity. For a given value of this quotient, L has to be chosen large enough, so that the error due to the reading of s is small. It is seen from fig. 3 that the ideal form of a testbody would be dumb-bell shaped with its masses concentrated at the force maxima. The standard would form one end and the substance being investigated the other. Such an ideal testbody is practical only for solid substances. For liquids the volumes must be extended on both sides of the force maxima, since the container tube itself contributes to the mass M but not to the integral J. In practice the ratio of tube mass to liquid volume decreases with increasing length. The optimum length depends on the tube material and how thin walled the tube can be made. The filling of the tube can not be reproduced without small deviations in the liquid volume. These volume differences are located largely at the end of the tube. For this reason it has been found advantageous to make the tube somewhat longer, so that the ends reach a weaker region of the force field, thus diminishing the errors. About 70 % of the ideal sensitivity is obtained with the plexiglass tube described below. This figure can be increased as the filling method is improved. According to our calculations only about 10—20 % are to be gained in sensitivity with a larger airgap and a tube, whose dimensions approximate the shape of the force field.

A tube with only a single partition shows a labile equilibrium in the magnetic field with some materials. Attempts to stabilize the tube are based on the following consideration:

In fig. 3 a boundary between two materials, with volume susceptibilities $\varkappa_1$, and $\varkappa_2$ respectively and with cross section A, is indicated. If the boundary which is perpendicular to the x-axis and has the original coordinate x, moves a small distance $\delta\,x$ in the positive direction, and if $H_y(x)\,\frac{\partial\,H_y(x)}{\partial\,x} = \varphi(x)$, the change in the magnetic force can be written approximately as

$$\delta\,f_+ = A\,\delta\,x\,(\varkappa_1 - \varkappa_2)\cdot\varphi\left(x + \frac{\delta\,x}{2}\right).$$

Since the tube is symmetrical and $\varphi(x)$ antisymmetrical the term from the negative side is

$$\delta\,f_- = A\,\delta\,x\,(\varkappa_1 - \varkappa_2)\cdot\varphi\left(x - \frac{\delta\,x}{2}\right).$$

Summing up and dividing by $\delta\,x$ gives the stabilizing term

$$\frac{\partial\,f}{\partial\,x} = 2\,A\,(\varkappa_1 - \varkappa_2)\cdot\varphi(x) \tag{4}$$

If this term is negative, it means that the force $\delta\,f = \frac{\partial\,f}{\partial\,x}\,\delta\,x$ has a stabilizing effect. Since $\varphi(x)$ is negative for $x > 0$ the force is negative if $\varkappa_1 > \varkappa_2$. Thus a less diamagnetic or a paramagnetic substance at the center of the tube is stabilizing. At the end of the tube $\varkappa_2$ is the susceptibility of the air, which is paramagnetic and hence always tends to make the tube unstable.

The total stability of the tube $\left(\frac{\partial F}{\partial x}\right)$ is a sum of forces like that defined by equation (4) plus one term $\frac{\partial f_g}{\partial x} < 0$, due to gravity and which is always stabilizing. This is expressed by the equation

$$\frac{\partial F}{\partial x} = \sum_n \frac{\partial f_n}{\partial x} + \frac{\partial f_g}{\partial x}, \tag{5}$$

where n is the index for the different boundaries. If a surface is not perpendicular to the x-axis, $\frac{\partial f_n}{\partial x}$ is an integral which can be solved graphically from the curve on fig. 3.

By the aid of equation (5) it is easy to construct a tube with a desired stability. We have found that a stability of 7–10 dyne/cm is optimal. A higher value will decrease the accuracy of the readings, and a lower value may cause the tube to be unstable with some solutions.

The stability can be determined experimentally from the swinging frequency of the bifilar pendulum (formed by the tube and its suspension wires) in the field. Such measurements have been made and check equation (5) quite well. Since the right hand side of this equation contains terms relating to the volume susceptibility of the solution, it is possible to use frequency measurements for a rough estimation of $\varkappa$.

The first tube used in the apparatus was made of glass. It was, however, not very symmetrical, the weight was rather high (0.7 g) and there were difficulties in closing the tube after filling. Because of these imperfections we have used plexiglass and aluminium tubes. For plexiglass we determined $\varkappa = -0.770 \; 10^{-6}$ cgs and $\varrho = 1.187$ g/cm^3. The corresponding values for aluminium can be found in the International Critical Tables or similar sources.

In fig. 8 the details of the plexiglass tube are shown. Two sample containers (*B*) are glued on to a hollow central section (*A*). In this way a stabilizing cavity filled with air is formed in the middle of the tube. Two end plugs (*C*) are wet with a small amount of chloroform and instantly placed in sections (*B*) in the position indicated by the dotted lines. They are placed 0.50 mm from the ends in order to give room for the screw formed lids (*E*). A ring (*D*) of aluminium, with surface marks at 15 degree intervals, is screwed over the central part of the tube. The main function of this ring is to reduce the zero force to a minimum. The ring will serve to damp the movements of the tube and also stabilize it, since aluminium has a slightly positive susceptibility.

A small piece of sheet-platinum projecting out only a few tenths of a millimeter is fixed to one end of the tube. This forms the indicator observed in the microscope (*d* of fig. 1).

All parts of the tube have to be carefully washed in a hydrochloric acid solution before use to dissolve any traces of metallic iron that may be left from the machining of the tube.

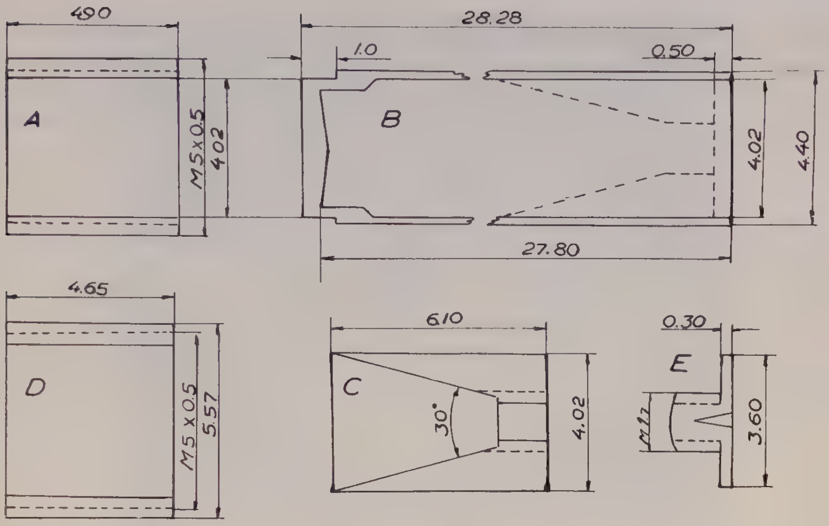

Fig. 8. Details of the plexiglass tube.

The weight of the plexiglass tube itself is about 0.4 g, and the volume of each half is 0.3 ml, so that the total weight of the tube filled with water is about 1 g. The reproducibility of the filling with water solutions is better than 0.1 %, and no evaporation can be observed within 20 minutes after the filling.

The tube of plexiglass can be used only for aqueous solutions, since many organic solvents will destroy it. For the latter we have made a similar tube of aluminium. In this case the end plugs are formed as screwable muffs, and the threads are seated with a glue of gelatine dissolved in glacial acetic acid. Water can not be used in this tube as it will dissolve the glue.

Mounting of the tube

The suspension wires are made of tungsten, 0.01 mm in diameter. These are the same as those that are used in the double spiral filaments of common lamps. Two lengths of about 130 cm each are fixed to the unrolling cylinders with a glue of celluloid dissolved in acetone. Small weights of copper are attached to the free ends to stretch the wires. The ends of the tube are inserted into loops, about 13 mm in diameter, at the lower ends of the wires. When the distance between the loops has been adjusted and the platinum indicator is in proper position, a loop of hair is made around each wire. These loops are pressed down against the tube, drawn together, tied and glued. Now the tube is adjusted by means of the guides to swing freely in the box. After filling with water it is adjusted again. When the tube is in the right position, the image of the indicator in the microscope should be sharp both with and without magnetic field. At this point the adjustment of the aluminium ring is made.

The distance from the point, where the wires leave the guiding cylinders, to the tube axis is 1054 mm.

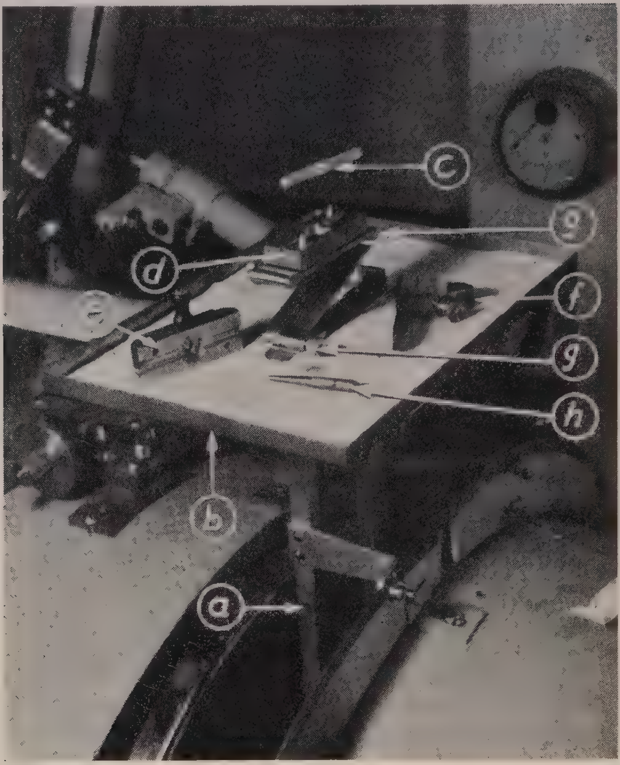

Fig. 9. Equipment for the filling of the tube.

Filling of the tube

The air shielding is removed and the tube is wound up over the magnet housing to make it accessible for filling. See fig. 9. The table (*b*) is placed on the two fixed shields (*a*). Then the tube (*c*) is lowered into the groove of the bottom part (*d*) of the brass block. The upper part of the block (*e*) is put into position over the tube and fixed by the springs (*f*). Weight is applied only over the area of the end plugs, so that the thin walls of the tube are not deformed. The brass block serves to keep the temperature of the tube constant during the subsequent operations. It is mounted on two joints (*g*), so that the tube can be placed vertically in both directions for filling.

The two lids are removed by means of the small screwdriver (*h*). The tube is placed vertically in one direction, the old filling in the upper part is aspirated, the tube is washed a few times with water and dried by passing air through it. Then the tube is filled with the new solutions by means of a 1 ml hypodermic syringe. Filling the tube in this way minimizes the occurrence of air bubbles. The other side is handled in the same way, and the screw lids are replaced. The drops of liquid at the ends of the tube are now removed by a small piece of filter paper. After the brass block has been opened, the tube is lifted up and the table taken away. The tube is lowered into the box, the shielding is put into place and the measurement made.

The time from introduction of the sample into the tube to the first observation in the magnetic field requires about 2 min.

Technique of observation

By moving the upper prism of the vertical microscope tube the image of the edge of the left endscrew of the box is moved to a certain scale division of the ocular scale. The sample tube is then moved, so that its indicator is 30 scale divisions from the screw. The reading on the micrometer is taken as s_0. When the current is switched on and adjusted to 20 A, the tube is brought back to its original position and a new reading, s_{20}, is taken. The difference $s_{20} - s_0$ multiplied by the actual mass of the tube is a measure of the magnetic force acting on the tube:

$$p_n = m\,(s_{20} - s_0) \tag{6}$$

In the mass, m, of the tube the weight of the wires (1.6 mg each) is included. The total weight of the glue, estimated to be 0.5 mg, is also included.

Measurement of substances dissolved in buffer requires a preliminary measurement, p_I, with buffer in both sides of the tube. A second measurement, p_{II}, is then made with the sample in the right side. A new measurement of p_I is then made. The difference, p, between p_{II} and the mean of the p_I-measurements is a measure of the force due to the difference in volume susceptibility between solution and buffer. This relation is written

$$\Delta\varkappa = \varkappa_s - \varkappa_b = k\,p. \tag{7}$$

$\varkappa_b$ is found by measuring the buffer against water. We have not found any appreciable effect of dissolved air on the value $\varkappa_{\text{water, } 20^\circ\text{C}} = -0.7200 \cdot 10^{-6}$ cgs. The expected dependence of the fourth figure has only a very small influence on the molar data evaluated from the measurements.

It has been found to increase the accuracy, if both sides are refilled for every p_I and p_{II} determination. A determination of p takes about 15 minutes.

Calibration

The constant k of equation (7) is determined after calibration with a known standard. A solution of nickel chloride in water is very suitable for this purpose. The concentration of nickel is determined by precipitation with dimethylglyoxime. As the molar constant for nickel chloride we use $X_{\text{NiCl}_2,\, 20^\circ\text{C}} = 4434 \cdot 10^{-6}$ cgs, which is a mean of the values found by WEISS and BRUINS (5), BRANT (6), and NETTLETON and SUGDEN (7). The volume constant of the solution is calculated under the assumption that Wiedemann's law and Curie's law are valid. It was proved that k is a real constant by measurement of several dilutions of the stock solution. Traces of ferromagnetic material in a test solution or on the tube can easily be detected by comparing the current dependence of s with the normal curves found with the standard solutions.

Errors

We have found it important to fill the sample tube at the same temperature at which the magnetic measurements are made. Because of the difference in the thermal expansion coefficients of water and plexiglass a temperature change after filling will deform the tube, tending to press out solution or suck in air.

With the technique described here the statistical mean errors for a single determination of s are ± 2 μ in s_0 and ± 8 μ in s_{20}. Five calibrations gave a mean error of the mean of p of ± 7 $g\,\mu$ and a maximum deviation of about 20 $g\,\mu$.

These errors are due to several sources, the most important being (mentioned in the approximative order of importance) temperature effects, differences in the fillings, fluctuations in the magnetizing current, errors in the scale readings, and material lost from the screw lids.

Sensitivity

The sensitivity of the force measuring system is about the same as for a microbalance. 1 μ on the micrometer corresponds to a magnetic force of 10^{-3} dyne.

The value of k is about $2 \cdot 10^{-11}$ cgs/g μ, which is the susceptibility per unit of p. Thus the mean error in $\Delta \varkappa$ is $\pm 1.5 \cdot 10^{-10}$ cgs when a few determinations are made. A single determination gives the accuracy $\pm 4 \cdot 10^{-10}$ cgs. This means that with a solution containing 0.25 mg Fe/ml it is possible to determine the molar susceptibility of iron within the limits $\pm 100 \cdot 10^{-6}$ cgs in a single determination. In the measurements on myoglobin carried out at this laboratory (8) this corresponds to 25 mg of protein. This can be compared with the measurements on hemoglobin (same iron content as for myoglobin) made by CORYELL, STITT and PAULING (9). Their macromethod had only half of our accuracy and required 10—20 g hemoglobin per determination. They could utilize a single sample for a whole titration curve determination, but all of it was destroyed at extreme pH-values. With our micromethod it is possible to get 40 points on such a curve with only 1 g of hemoglobin (= 3.4 mg of iron) and most of the material can be recovered as only a portion of it is brought to extreme pH.

If our present method is compared with the one used by HOWLAND and CALVIN (2, 3) it is found that the accuracy of the two methods is about the same. However, the same amount of dissolved paramagnetic material gives a 30 times larger force in the apparatus described here, even though a 3 times more diluted solution is utilized.

With an adequate temperature control and stabilized magnetizing current it will be possible to increase the accuracy of the method at least 5 times.

SUMMARY

A micromethod for magnetic susceptibility measurements on solutions has been developed. It is a variation of the Gouy-method employing a horizontal sample tube with bifilar suspension. The tube is short and kept in the same position during the measurements by moving the upper fixing points of the

suspensions. The displacement of the latter is a measure of the magnetic force. Both water and organic solvents can be used depending on the material of which the sample tube is made. A single determination requires only 0.3 ml of solution and can be completed within 15 minutes with an error in $\Delta \varkappa$ of $\pm 4 \times 10^{-10}$ cgs.

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